Source Location through Radiological Monitoring

(System Design and Concept of Operations)

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Introduction

The accurate determination of the location from which radiological materials may have been released based only upon downwind measurements of airborne material depends upon the material's horizontal transport as well as its dispersion. For instance, no meteorological data nor model calculation can be used to determine if a radiological measurement at ground-level was the result of transport in the lower layers of the atmosphere or the upper-layers with subsequent mixing to the ground. Horizontal transport pathways can have large variations with altitude. Because of the irreversible nature of the dispersion processes, any receptor to source calculation, in contrast with a source to receptor calculation, will have greater uncertainty.

Uncertainty can be reduced with more information. For instance the time of the release will narrow the number of potential meteorological scenarios that can result in transport from the source to the measurement location. More measurement information, in terms of the number of samples at a site or the number of sites with a detectable concentration, permits greater precision in the source determination through regression or vector triangulation techniques. Note that greater temporal resolution in the sampling data also improve accuracy as well as precision. Sample resolution of six hours or less is essential due to the diurnal cycle in meteorological processes.

In the following sections the process of finding a source location using only air concentration measurement data will be demonstrated by example using both trajectory techniques and dispersion model simulations. A subset of the results from a long-range dispersion experiment using inert perfluorocarbon tracers conducted by the European community in 1994 to simulate a nuclear accident will be used for the demonstration. One hundred sixty-eight ground-level samplers collected 3-h samples for three days at sites in France, Germany, Poland, Hungary, and several other European countries. Twenty countries with real-time modeling capability participated by submitting dispersion calculations to the operations center at the conclusion of the experiment. The NOAA model results from those calculations will be used in this example. Although the results have not been officially released, there is sufficient information available to demonstrate source attribution calculations.

The Problem

From the available data, only three widely separated sites are assumed to have detected the release. Only data from these sites as shown in Table I will be used in the example calculations. Note that the reported concentrations are only preliminary, cannot be quoted, and will certainly change with the release of the final report.

Table I. Time series of concentration measurements (ngm^{-3}) used simulate the results from a limited radiological monitoring network.

Date	UTC	Cervena Czech Rep	Llchow Germany	Beek Netherlands
10/23	1600	0.0	0.0	0.0
	1900	0.0	0.0	0.0
	2200	0.0	0.0	0.0
10/24	0100	0.0	0.0	0.0
	0400	0.0	0.0	0.0
	0700	0.0	0.0	0.0
	1000	0.0	0.0	0.017
	1300	0.0	0.0	0.20
	1600	0.0	0.0	0.08
	1900	0.013	0.052	0.0
	2200	0.0	0.12	0.50
10/25	0100	0.033	0.11	0.53
	0400	0.0	0.08	0.16
	0700	0.07	0.20	0.0
	1000	0.17	0.30	0.0
	1300	0.35	0.27	0.0
	1600	0.35	0.19	0.0
	1900	0.42	0.07	0.0
	2200	0.43	0.0	0.0
10/26	0100	0.36	0.0	0.0

The measurement results clearly show that the pollutant cloud was first detected in the Netherlands and nine hours later simultaneously in Germany and the Czech Republic. The problem is now to determine the location and time of the release, and perhaps the amount of material released. We will assume no other information is available besides routine meteorological data fields.

Step 1 - Determine the Upwind Sector

A simple backward trajectory calculation is a good way to determine which regions are upwind of the receptor locations. A back-trajectory is calculated from a point in space and time by computing a parcel's motion using wind velocity vectors of opposite sign. Hence the trajectory represents the path that air would have passed over before arriving at the receptor. However since wind direction may change considerably with height, calculations are made simultaneously at three different levels above ground: 0.5, 1.5, and 3 km. One can usually assume that if the winds are similar at different heights then vertical mixing is strong. Large direction changes indicate less mixing and hence greater uncertainty about the proper transport pathway. Back-trajectories for the three locations are shown in Figs. 1-3, each using a single starting time, about mid-way through the period of dete ctable measurements.

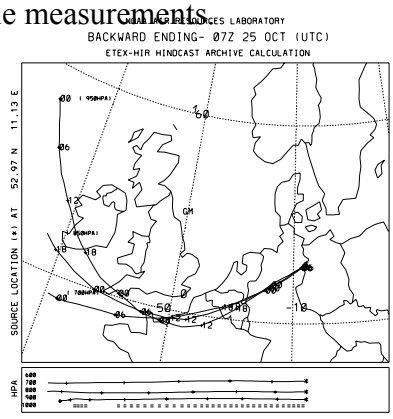

Figure 1 Germany

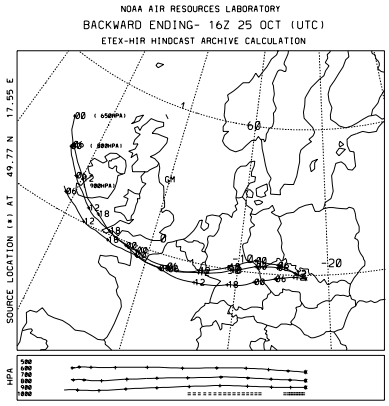

Figure 2 Czech Republic

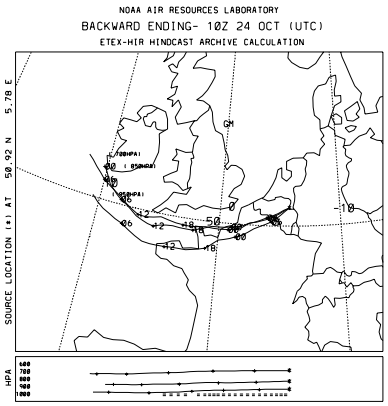

Figure 3 Netherlands

Trajectories from all three locations converge near the western coast of France. Remarkably trajectories at the three levels are very similar, indicating a high level of confidence in the transport direction. The duration of travel to the French coast indicates the material passed over that location at times ranging from 1800 on the 23rd through 1200 on the 24th. However the convergence point does not imply the source location as any area

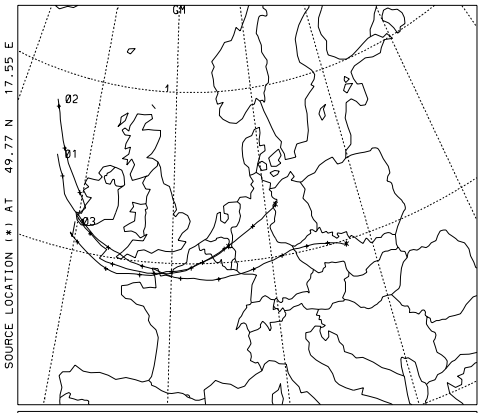

Figure 4 Average Trajectories

upwind from that point is a potential release location.

These results can be more clearly illustrated when the trajectories at all levels are averaged by site and plotted together as shown in Fig. 4. Considering that trajectory uncertainty may be as much as 25% of the distance along the trajectory, potential release locations can be in southern England, Ireland, ocean areas, as well as the French coast. The overlap of the trajectory from Germany and the Netherlands is purely coincidental.

Another aspect of the trajectory calculation is their persistence in time. In the previous illustrations only one time, the time at the center of the period during which above background concentrations were detected was used for the calculation. However trajectories should be calculated corresponding with multiple times, before, during, and after the detection period. Spatial persistence of the trajectories in time would indicate higher confidence in the indicated upwind sector. This is simply illustrated in Fig. 5, where back-trajectories were calculated from the Czech Republic sampler, 24 h before (marked -1), and 24 h after (marked +1) the calculation shown in Fig. 2 (marked 0). These were time periods when no detectable concentrations were evident. For both of these days the upwind sectors were much further to the south. In an operational mode, trajectories should be calculated at least every six hours to correspond with the temporal resolution of the meteorological data. If more information were to be available, for instance the time of the event, the source location could be narrowed even further. We will assume no such information at this time.

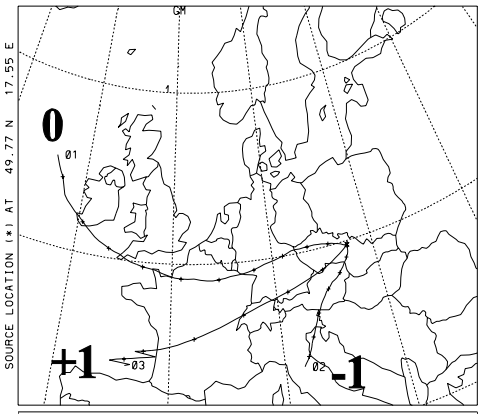

Figure 5. Temporal Variation

Step 2 - Determine the Release Time

Conceptually the calculation of a release time and narrowing the upwind sector to a more finite region for source location is treated in the same way. It requires a leap beyond the simple trajectory concept. At this stage we know the approximate source region, which may extend a considerable distance west of the French coast -- because we do not know the release time. We now select a finite number of "potential" source locations. Transport and dispersion calculations will be made from each of these locations assuming a unit emission of material. Calculations are performed for the period corresponding to the sampling and air concentration predictions are made for each sampler and time period. However because the exact release time is unknown, a separate calculation is performed at regular 6-h intervals for the time period in question as determined in the previous step: Oct. 23 through Oct. 24.

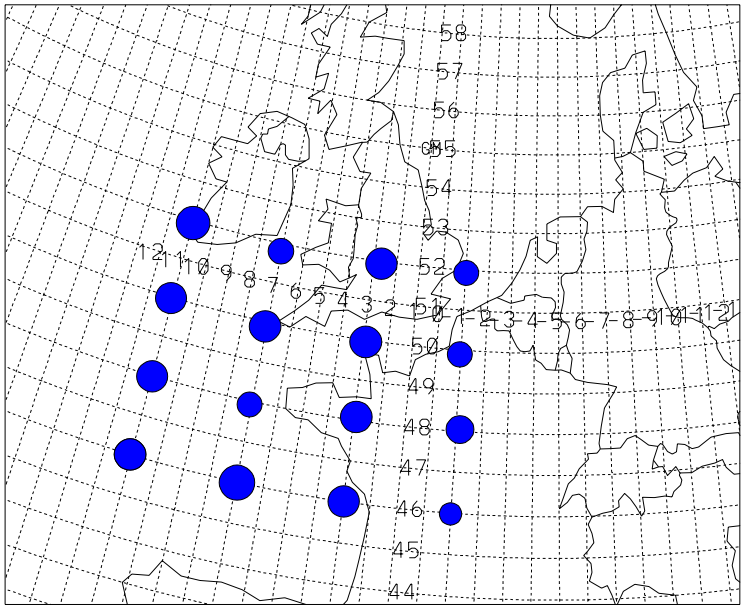

Figure 6 Source Locations

The potential sources are shown in Fig. 6. Arbitrary locations are selected at intervals of 2 deg latitude and 4 deg longitude between 1E and 11W and 46N to 52N, for a total of 16 source locations. With 4 calculations per day (0000, 0600, 1200, and 1800 UTC) for two days, there are a total of 128 independent source calculations which provide 20 concentration predications at each sampling location (see Table I). Each calculation was assumed to be a continuous emission for six hours consisting of a total of one unit.

The question is now only which source and starting time combination gives the best fit to the measured sampling data using simple correlation coefficients. Clearly more measurement stations, in different locations, will provide more opportunity for various starting locations to produce different predictions at the same time. If the time of the event is already known, then one essentially skips this step, since all that is necessary is to determine which starting location gives the best fit to the measurements.

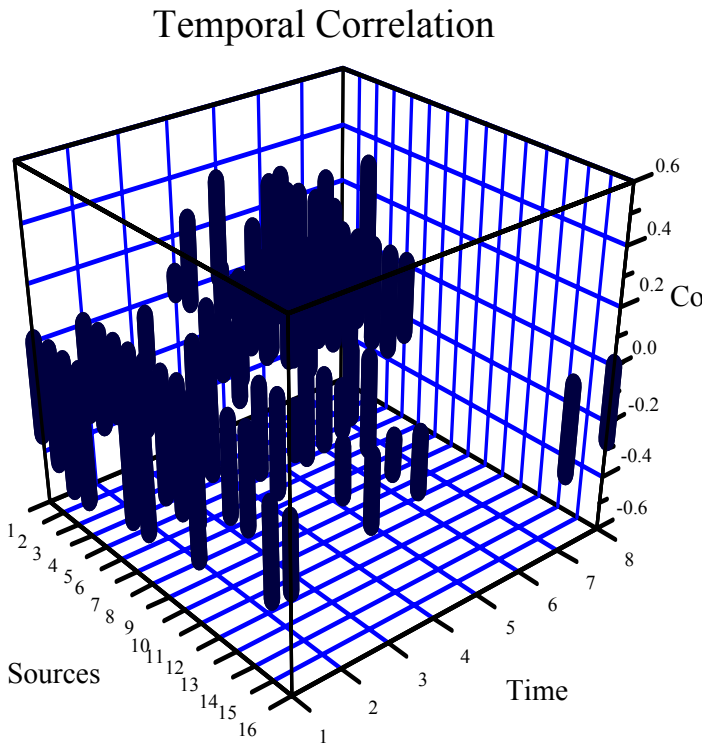

Figure 7 Release Time Determination

The correlation results are summarized in Fig. 7. Because we are only interested in finding the release time, the 16 source locations are simply shown along the x-axis without regard to spatial location. The eight simulation start times are given along the y-axis. Period one represents a calculation starting at 0000 UTC on 10/23. Period two starts six hours later. Correlations are essentially zero or negative for the first three periods. Negative correlations indicate model predictions when nothing was measured or no predictions when detectable concentrations were measured. This is a clear sign that the particular source-time

combination is not correct. Correlations for periods 4, 5, and 6 show substantial positive values at several starting locations. Periods 7 and 8 drop again to insignificant values. Clearly the period of October 23, 1800 UTC through October 24, 1200 UTC shows the greatest match between model calculations and observations.

Step 4 - Determine the Source Location

At this step we either knew the release time from other information, or made a determination from the previous step. The highest correlation coefficient, 0.54, occurred during Period 4. Therefore all model source calculations that were started during Period 4 are used to further narrow the location of the source. The previous step may have been bypassed in that all source combination simulations were already calculated for only this starting time.

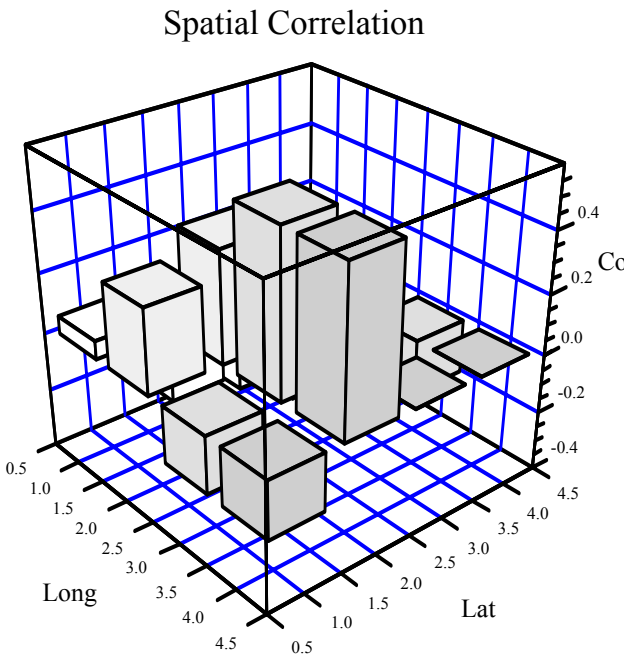

Figure 8 Source Location

The Period 4 spatial correlation results are shown in Fig. 8. The region of the highest correlations is the second row of starting locations - 48N. With the exception of one point, starting locations at other latitudes show essentially no correlation. This result may have been anticipated to some extent, in that the trajectories indicated less uncertainty in the north-south component than the east-west component. However, there is another factor to consider: the duration of the release. A long-duration release will spread out the source location uncertainty in the along-wind direction because a match to the measurements can occur for other locations that are displaced by no more than the average wind speed times the duration of the actual release.

How well did the model computations and analysis methods match what is known about the source? The release occurred near Rennes (48N, 2W), starting at 1600 UTC on the 23rd through 0400 on the 24th - a 12 hour duration. The earlier trajectory results showed transport of about 8 deg longitude over 12 hours. Therefore the additional two-grid point uncertainty in source location at 48N can in part be attributed to the long-duration emissions. It is wise to remember that there is considerable uncertainty in these calculations and more sophisticated statistical methods might yield more precise results, while fewer detailed measurements, or more complex meteorological situations will reduce the accuracy.

Step 5 - Determine the Release Amount

The final step can be an estimate of the emission amount. Model simulations were conducted using a unit emission for a six hour period. The ratio of the average concentration measured at a sampler to the average calculated concentration yields the factor by which the assumed model unit emission must be multiplied to predict the correct concentration. This method is only as accurate as the model calculation. Averaging the results from the three sampling sites for the starting locations along 48N indicate emissions from 100 to 250 kg. Because correlations were high for 2-3 consecutive time periods, this suggests a total release in the range of 300 to 750 kg. The actual release was 340 kg.

Summary

A simple methodology was suggested to permit the estimate of source location and time given a limited number of air concentration measurements. A sample calculation was shown using actual measured air concentration data from a known source. The process can be summarized as follows:

- An event is detected in the sampling network.
- Compute back-trajectories to straddle the period of detectable measurements.
- Select a potential large-scale source region based upon coherent trajectory patterns.
- If the event time is unknown use trajectories to select a release time range.
- Select the location of "pseudo" source points for hypothesis testing.
- If the event time is unknown...
  Run concentration simulations for each source and starting time combination.
  Use the correlation between model and measurements to determine the time.
- Else...
  Run concentration simulations for all source combinations at the event time.
- Use the correlations from each source point to isolate most likely source location.
- Using the ratio of measurements to model predictions estimate the strength of the release.